National Aeronautics and Space Administration

An Evolvable Mars Campaign

Jason Crusan
Director, Advanced Exploration Systems

Strategic Principles for Exploration Implementation

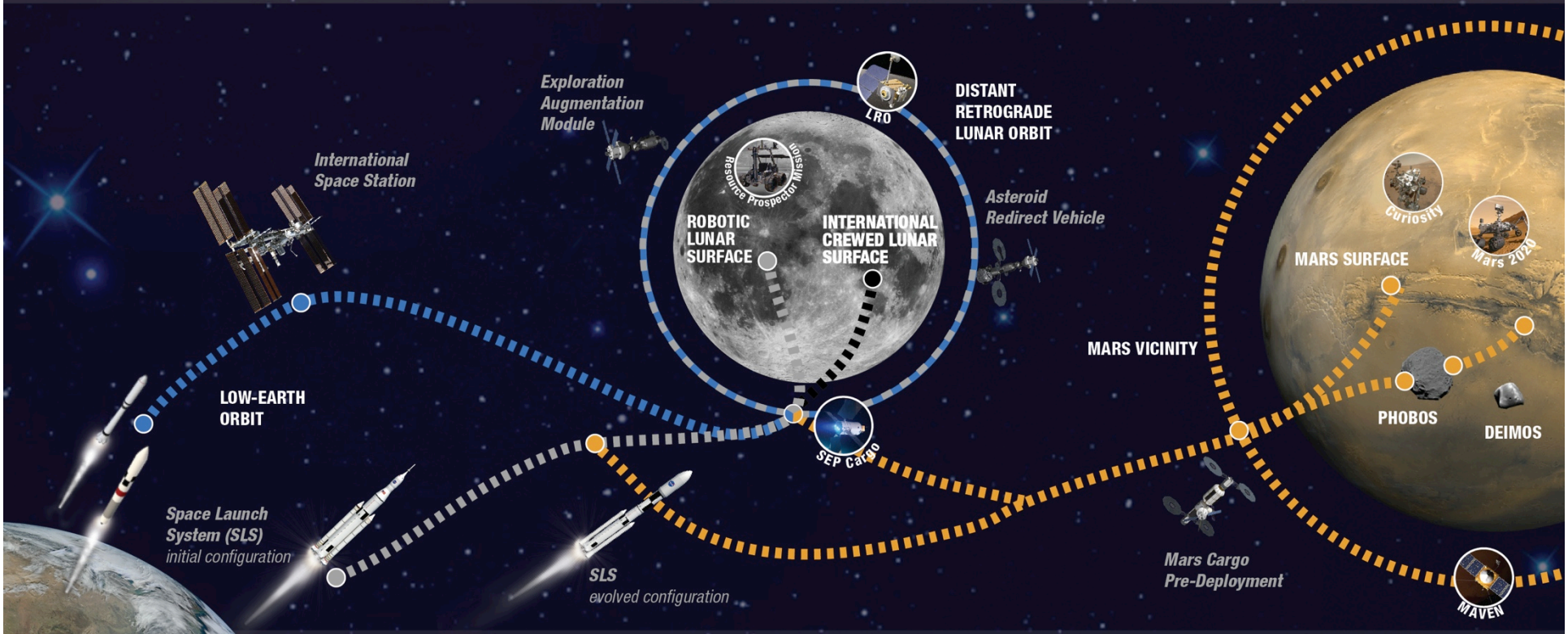
Six key strategic principles to provide a sustainable program:

1. Implementable in the ***near-term with the buying power of current budgets*** and in the longer term with budgets commensurate with economic growth.
2. Application of ***high Technology Readiness Level*** (TRL) technologies for near term, while focusing research on technologies to address challenges of future missions
3. ***Near-term mission*** opportunities with a defined cadence of compelling missions providing for an incremental buildup of capabilities for more complex missions over time
4. Opportunities for ***US Commercial Business*** to further enhance the experience and business base learned from the ISS logistics and crew market
5. ***Multi-use, evolvable*** Space Infrastructure
6. Significant ***International and Commercial participation***, leveraging current International Space Station partnerships

EVOLVABLE MARS CAMPAIGN

A Pathways Approach to Exploration

EARTH DEPENDENT | PROVING GROUND | EARTH INDEPENDENT



THE TRADE SPACE

Across the Board | Solar Electric Propulsion • In-Situ Resource Utilization (ISRU) • Robotic Precursors • Human/Robotic Interactions • Partnership Coordination • Exploration and Science Activities

Cis-lunar Trades
- Deep-space testing and autonomous operations
- Extensibility to Mars
- Mars system staging/refurbishment point and trajectory analyses

Mars Vicinity Trades
- Split versus monolithic habitat
- Cargo pre-deployment
- Mars Phobos/Deimos activities
- Entry descent and landing concepts
- Transportation technologies/trajectory analyses

MARS IS HARD

THERE & BACK

- The ability to launch a very powerful rocket
- High-reliability spacecraft systems
- Size requirements of crew capsule
- Validation of performance of SLS and Orion in the deep space environment *(hotter, colder, radiation)*
- Deep space navigation
- Rendezvous and docking
- Life support systems
- High speed re-entry

HAPPY & HEALTHY

- Air, water, food
- Waste containment
- Psychological impact
- Low- / no-gravity
- Medical emergencies
- Bone loss
- Radiation
- Ocular degeneration
- Hygiene

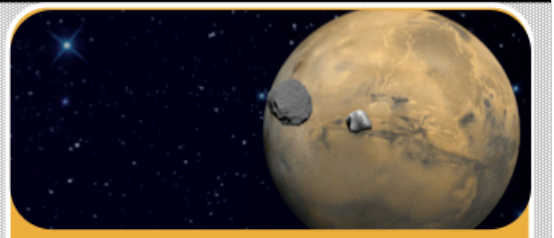
WELL EQUIPPED & PRODUCTIVE

- Sample handling
- Microgravity operations
- Space suits
- Advanced training and tools
- Mission planning
- Situational awareness and decision making
- Crew relationships

Evolutionary Capabilities

EARTH RELIANT
Return to Earth: hours

PROVING GROUND
Return to Earth: days



EARTH INDEPENDENT
Return to Earth: many months

Transportation	EARTH-BASED SUPPORT: HIGH *Low-Earth Orbit*	EARTH-BASED SUPPORT: LIMITED *Cis-lunar Space*	EARTH-BASED SUPPORT: NEGLIGIBLE *Mars and Beyond*
Crew Transit	• Routine crew rotations via international and industry partners • Earth Re-entry: 3,000°F	• 2-4 crew launch aboard evolvable Space Launch System • Orion Earth Re-entry: 5,300°F	• Up to 6 crew launch aboard Space Launch System • Orion Earth Re-entry: 5,500°F
Cargo Transit	• Routine cargo deliveries to LEO via industry and international partners	• 105t SLS to lunar vicinity	• 130t SLS to Mars and beyond • Crew must live and work without resupply from Earth
Propulsion & Energy Storage	• Large scale use of solar panels	• Demonstrate potential resource utilization techniques • Demonstrating high-power, advanced solar electric propulsion	• Potential to expand resource utilization • Utilizing large-scale solar electric and other advanced propulsion
Planetary rendezvous & landings	• Planetary rendezvous with strong gravity field	• Deep Space Rendezvous; gravity free • Lunar surface landers	• Phobos/Deimos micro-gravity rendezvous • Mars entry, descent, landing on surface

Mars 2020
Collaboration Among SMD, HEOMD and STMD

Mars 2020 will seek signs of past life on Mars, collect and store a set of soil and rock samples that could be returned to Earth in the future, and test new technology to benefit future robotic and human exploration of Mars.

HEOMD / SMD / STMD are jointly sponsoring investigations to address high priority strategic knowledge gaps and technology development objectives for Human Exploration

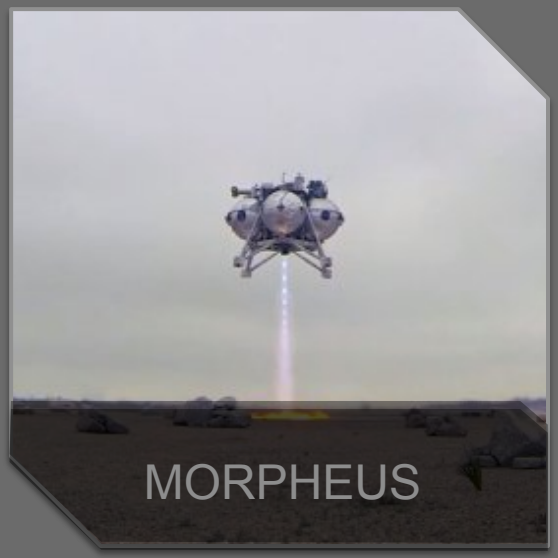
- Mars Entry, Descent and Landing Instrumentation (MEDLI) to refine atmospheric entry models to inform future landing system design
- Exploration technology payloads that make significant progress towards filling at least one major Strategic Knowledge Gap.

Lunar CATALYST

Lunar CArgo Transportation And Landing bY Soft Touchdown

BRINGING THE MOON INTO EARTH'S ECONOMIC SPHERE

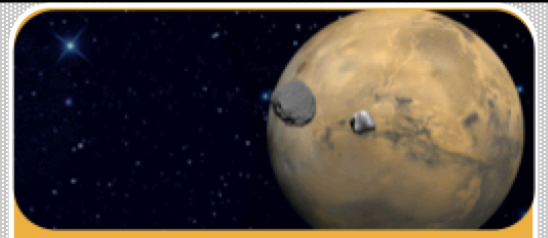
Accelerating private-sector lunar landing capabilities with NASA expertise using public-private partnerships



STATUS

Currently evaluating proposals with partner selections in April and executed agreements in May 2014

Evolutionary Capabilities

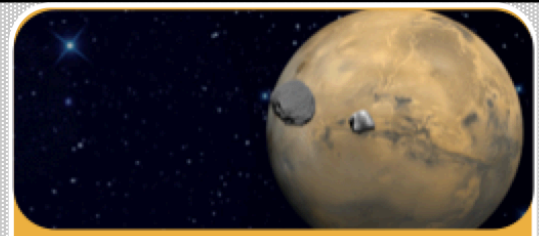


	EARTH RELIANT Return to Earth: hours	PROVING GROUND Return to Earth: days	EARTH INDEPENDENT Return to Earth: many months
Working In Space	EARTH-BASED SUPPORT: HIGH *Mastering the Fundamentals*	EARTH-BASED SUPPORT: LIMITED *Pushing the Boundaries*	EARTH-BASED SUPPORT: NEGLIGIBLE *Exploring Independently*
Exploration and Science	• Microgravity science and human physiology research	• Sampling asteroid for return to Earth for analysis	• Mars moons and surface exploration and search for life with in-situ analysis
Communicating with Earth	• Immediate and continuous support from mission control	• Limited delay with minimal crew impact	• Independent and self-reliant crew operates with up to 40 min. delay
Spacewalk and Mobility	• Zero-g outside spacecraft for short distances	• Zero-g systems for short-distance, exploration	• Surface exploration in partial gravity with longer distance and duration
Spacecraft Assembly & Maintenance	• Crew-assisted ISS Assembly • Frequent deliveries & servicing	• Limited deliveries requires more efficient systems with common, interchangeable parts	• Maintenance with only the parts and tools they carry or produce in-situ
Human-Robotic Interactions	• Testing safety and control methods for efficient human-robotic teams	• Human- robot teams, with periods where robots are left alone	• Pre-deployed equipment depends on robots until humans arrive, then human-robot teams share critical tasks
In-situ Resource Utilization	• Recycle and reuse water and trash	• Learning to recycle destination resources for fuel, water, oxygen, and building materials	• Crew harvests destination resources to create fuel, water, oxygen, and building materials

Evolutionary Capabilities

EARTH RELIANT
Return to Earth: hours

PROVING GROUND
Return to Earth: days



EARTH INDEPENDENT
Return to Earth: many months

Staying Healthy	EARTH-BASED SUPPORT: HIGH *Mission Duration: 6-12 months*	EARTH-BASED SUPPORT: LIMITED *Mission Duration: 1-12 months*	EARTH-BASED SUPPORT: NEGLIGIBLE *Mission Duration: 2-3 years*
Spacecraft Life Support Systems	• Developing onboard life support systems for long-duration missions	• Validating onboard recycling and regenerating life support systems without resupply	• Living and working in spacecraft that must fully support crew for years
Human Health and Performance	• Studying space environment health risks and testing solutions	• Applying health and performance risk mitigation techniques	• Living in space for years while maintaining crew health and performance
Autonomous Medicine	• Developing integrated medical capability and crew-reliant medical care	• Testing semi-autonomous integrated medical capability and crew-reliant medical treatment	• Autonomous medical capability and medical crewmember for diagnosis and treatment
Environmental Monitoring	• Testing on-board environmental monitors with ground validation	• Demonstrating onboard environmental monitoring systems (no sample return)	• Monitoring crew environment for hazards, eliminating environmental emergencies
Advanced Space Suits	• Testing next-generation space suits	• Demonstrating advanced space suits in deep space	• Conducting EVAs in unprecedented planetary environments

HUMAN EXPLORATION

NASA's Path to Mars

EARTH RELIANT

MISSION: 6 TO 12 MONTHS
RETURN TO EARTH: HOURS

Mastering fundamentals aboard the International Space Station

U.S. companies provide access to low-Earth orbit

PROVING GROUND

MISSION: 1 TO 12 MONTHS
RETURN TO EARTH: DAYS

Expanding capabilities by visiting an asteroid redirected to a lunar distant retrograde orbit

The next step: traveling beyond low-Earth orbit with the Space Launch System rocket and Orion spacecraft

MARS READY

MISSION: 2 TO 3 YEARS
RETURN TO EARTH: MONTHS

Developing planetary independence by exploring Mars, its moons and other deep space destinations